IEEE 802.15.4

Notes on Travis Goodspeed's
Phantom Boundaries and Cross-Layer Illusions in 802.15.4 Digital Radio

In[56]:=
```
Needs["PlotLegends`"]
```

Get chips from standards PDF

In[4]:=
```
table24 = {First[#], Take[#, {2, 5}], Drop[#, 5]} & /@
  {{0, 0, 0, 0, 0, 1, 1, 0, 1, 1, 0, 0, 1, 1, 1, 0, 0, 0, 0, 1, 1, 0, 1, 0,
    1, 0, 0, 1, 0, 0, 0, 1, 0, 1, 1, 1, 0}, {1, 1, 0, 0, 0, 1, 1, 1, 0, 1, 1, 0,
    1, 1, 0, 0, 1, 1, 1, 0, 0, 0, 0, 1, 1, 0, 1, 0, 1, 0, 0, 1, 0, 0, 0, 1, 0},
   {2, 0, 1, 0, 0, 0, 0, 1, 0, 1, 1, 1, 0, 1, 1, 0, 1, 1, 0, 0, 1, 1, 1, 0, 0, 0, 0, 1,
    1, 0, 1, 0, 1, 0, 0, 1, 0}, {3, 1, 1, 0, 0, 0, 0, 1, 0, 0, 0, 1, 0, 1, 1, 1, 0, 1,
    1, 0, 1, 1, 0, 0, 1, 1, 1, 0, 0, 0, 0, 1, 1, 0, 1, 0, 1}, {4, 0, 0, 1, 0, 0, 1, 0, 1,
    0, 0, 1, 0, 0, 0, 1, 0, 1, 1, 1, 0, 1, 1, 0, 1, 1, 0, 0, 1, 1, 1, 0, 0, 0, 0, 1, 1},
   {5, 1, 0, 1, 0, 0, 0, 1, 1, 0, 1, 0, 1, 0, 0, 1, 0, 0, 0, 1, 0, 1, 1, 1, 0, 1, 1, 0,
    1, 1, 0, 0, 1, 1, 1, 0, 0}, {6, 0, 1, 1, 0, 1, 1, 0, 0, 0, 0, 1, 1, 0, 1, 0, 1, 0, 0,
    1, 0, 0, 0, 1, 0, 1, 1, 1, 0, 1, 1, 0, 1, 1, 0, 0, 1}, {7, 1, 1, 1, 0, 1, 0, 0, 1,
    1, 1, 0, 0, 0, 0, 1, 1, 0, 1, 0, 1, 0, 0, 1, 0, 0, 0, 1, 0, 1, 1, 1, 0, 1, 1, 0, 1},
   {8, 0, 0, 0, 1, 1, 0, 0, 0, 1, 1, 0, 0, 1, 0, 0, 1, 0, 1, 1, 0, 0, 0, 0, 0, 0, 1, 1, 1,
    0, 1, 1, 1, 1, 0, 1, 1}, {9, 1, 0, 0, 1, 1, 0, 1, 1, 1, 0, 0, 0, 1, 1, 0, 0, 1, 0,
    0, 1, 0, 1, 1, 0, 0, 0, 0, 0, 0, 1, 1, 1, 0, 1, 1, 1}, {10, 0, 1, 0, 1, 0, 1, 1, 1,
    1, 0, 1, 1, 1, 0, 0, 0, 1, 1, 0, 0, 1, 0, 0, 1, 0, 1, 1, 0, 0, 0, 0, 0, 0, 1, 1, 1},
   {11, 1, 1, 0, 1, 0, 1, 1, 1, 0, 1, 1, 1, 1, 0, 1, 1, 1, 0, 0, 0, 1, 1, 0, 0, 1, 0, 0,
    1, 0, 1, 1, 0, 0, 0, 0, 0}, {12, 0, 0, 1, 1, 0, 0, 0, 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 0,
    1, 1, 1, 0, 0, 0, 1, 1, 0, 0, 1, 0, 0, 1, 0, 1, 1, 0}, {13, 1, 0, 1, 1, 0, 1, 1, 0,
    0, 0, 0, 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 0, 1, 1, 1, 0, 0, 0, 1, 1, 0, 0, 1, 0, 0, 1},
   {14, 0, 1, 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 0, 0, 0, 0, 1, 1, 1, 0, 1, 1, 1, 1,
    0, 1, 1, 1, 0, 0, 0, 1, 1, 0, 0}, {15, 1, 1, 1, 1, 1, 1, 0, 0, 1, 0, 0, 1,
    0, 1, 1, 0, 0, 0, 0, 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 0, 1, 1, 1, 0, 0, 0}}
```

In[89]:= **MatrixForm[chips = Last /@ table24]**

Out[89]//MatrixForm=

1	1	0	1	1	0	0	1	1	1	0	0	0	0	1	1	0	1	0	1	0	0	1	0	0	0	1	0	1	1	1	0
1	1	1	0	1	1	0	1	1	0	0	1	1	1	0	0	0	0	1	1	0	1	0	1	0	0	1	0	0	0	1	0
0	0	1	0	1	1	1	0	1	1	0	1	1	0	0	1	1	1	0	0	0	0	1	1	0	1	0	1	0	0	1	0
0	0	1	0	0	0	1	0	1	1	1	0	1	1	0	1	1	0	0	1	1	1	0	0	0	0	1	1	0	1	0	1
0	1	0	1	0	0	1	0	0	0	1	0	1	1	1	0	1	1	0	1	1	0	0	1	1	1	0	0	0	0	1	1
0	0	1	1	0	1	0	1	0	0	1	0	0	0	1	0	1	1	1	0	1	1	0	1	1	0	0	1	1	1	0	0
1	1	0	0	0	0	1	1	0	1	0	1	0	0	1	0	0	0	1	0	1	1	1	0	1	1	0	1	1	0	0	1
1	0	0	1	1	1	0	0	0	0	1	1	0	1	0	1	0	0	1	0	0	0	1	0	1	1	1	0	1	1	0	1
1	0	0	0	1	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	1	1	1	0	1	1	1	1	0	1	1
1	0	1	1	1	0	0	0	1	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	1	1	1	0	1	1	1
0	1	1	1	1	0	1	1	1	0	0	0	1	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	1	1	1
0	1	1	1	0	1	1	1	1	0	1	1	1	0	0	0	1	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0
0	0	0	0	0	1	1	1	0	1	1	1	1	0	1	1	1	0	0	0	1	1	0	0	1	0	0	1	0	1	1	0
0	1	1	0	0	0	0	0	0	1	1	1	0	1	1	1	1	0	1	1	1	0	0	0	1	1	0	0	1	0	0	1
1	0	0	1	0	1	1	0	0	0	0	0	0	1	1	1	0	1	1	1	1	0	1	1	1	0	0	0	1	1	0	0
1	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	1	1	1	0	1	1	1	1	0	1	1	1	0	0	0

Hamming distance, unshifted

In[90]:= **MatrixForm[UnshiftedHammingDistance = Outer[HammingDistance, #, #, 1] &[chips]]**

Out[90]//MatrixForm=

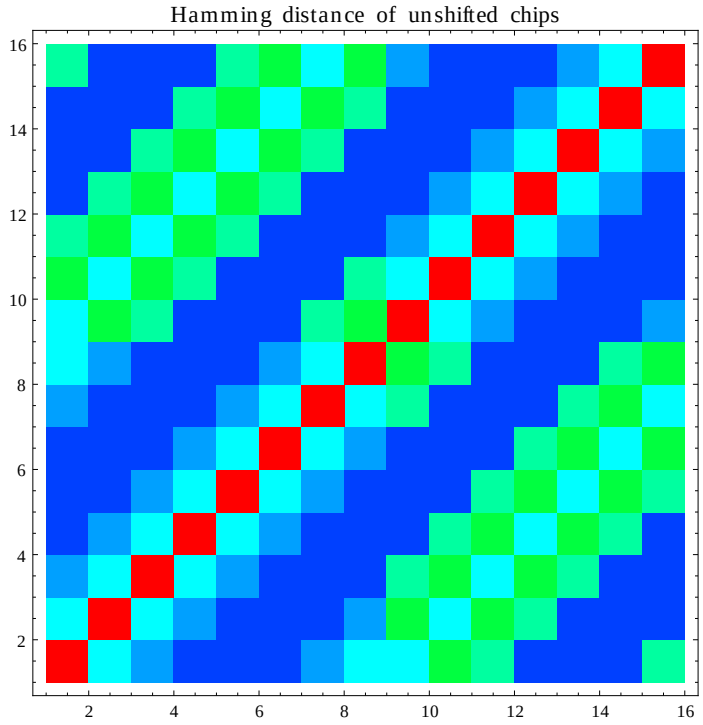
0	16	18	20	20	20	18	16	16	12	14	20	20	20	14	12
16	0	16	18	20	20	20	18	12	16	12	14	20	20	20	14
18	16	0	16	18	20	20	20	14	12	16	12	14	20	20	20
20	18	16	0	16	18	20	20	20	14	12	16	12	14	20	20
20	20	18	16	0	16	18	20	20	20	14	12	16	12	14	20
20	20	20	18	16	0	16	18	20	20	20	14	12	16	12	14
18	20	20	20	18	16	0	16	14	20	20	20	14	12	16	12
16	18	20	20	20	18	16	0	12	14	20	20	20	14	12	16
16	12	14	20	20	20	14	12	0	16	18	20	20	20	18	16
12	16	12	14	20	20	20	14	16	0	16	18	20	20	20	18
14	12	16	12	14	20	20	20	18	16	0	16	18	20	20	20
20	14	12	16	12	14	20	20	20	18	16	0	16	18	20	20
20	20	14	12	16	12	14	20	20	20	18	16	0	16	18	20
20	20	20	14	12	16	12	14	20	20	20	18	16	0	16	18
14	20	20	20	14	12	16	12	18	20	20	20	18	16	0	16
12	14	20	20	20	14	12	16	16	18	20	20	20	18	16	0

In[119]:= **hue32 = Hue[# / 32] &**

Out[119]= $\text{Hue}\left[\frac{\#1}{32}\right]\&$

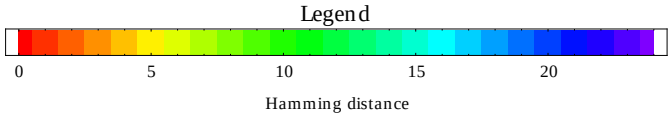
In[124]:=
```
ListDensityPlot[UnshiftedHammingDistance, InterpolationOrder → 0, ColorFunction → hue32,
 ColorFunctionScaling → False, PlotLabel → "Hamming distance of unshifted chips"]
```

Out[124]=



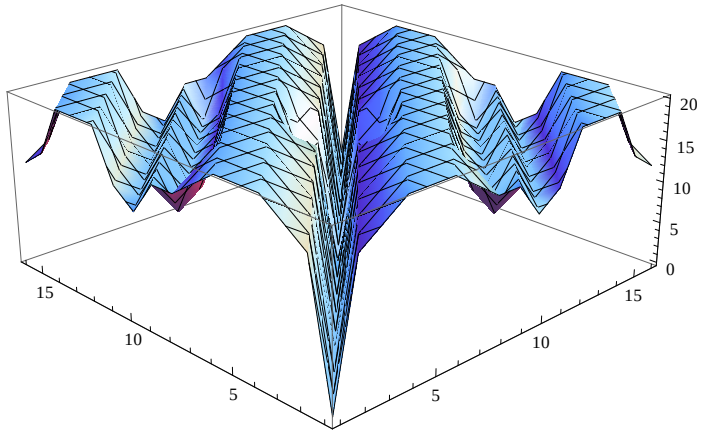
In[125]:=
```
ListDensityPlot[{#, 0, #} & /@ Range[0, 24], InterpolationOrder → 0,
 ColorFunction → hue32, ColorFunctionScaling → False, FrameTicks → {Automatic, None},
 AspectRatio → 1 / 25, PlotLabel → "Legend", FrameLabel → {"Hamming distance", ""}]
```

Out[125]=



In[94]:=
```
ListPlot3D[UnshiftedHammingDistance]
```

Out[94]=



Hamming distance with cyclic shifts

In[95]:=
```
Dimensions[chips]
```

Out[95]= {16, 32}

In[101]:=
```
Dimensions[cyclicchips = Function[chip, RotateLeft[chip, #] & /@ (Range[Length[chip]] - 1)] /@ chips]
```

Out[101]= {16, 32, 32}

In[102]:=
```
Dimensions[cyclichammings = Outer[HammingDistance, chips, cyclicchips, 1, 2]]
```

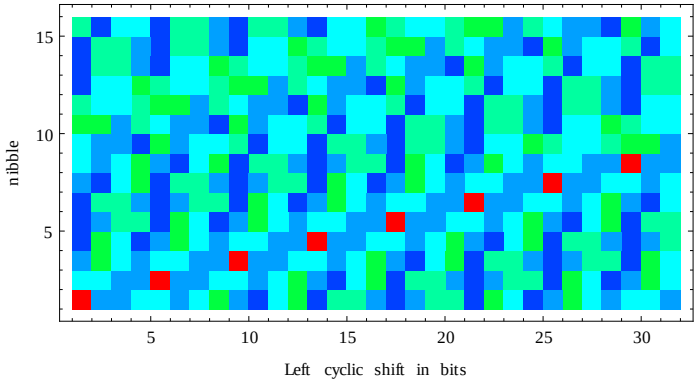
Out[102]= {16, 16, 32}

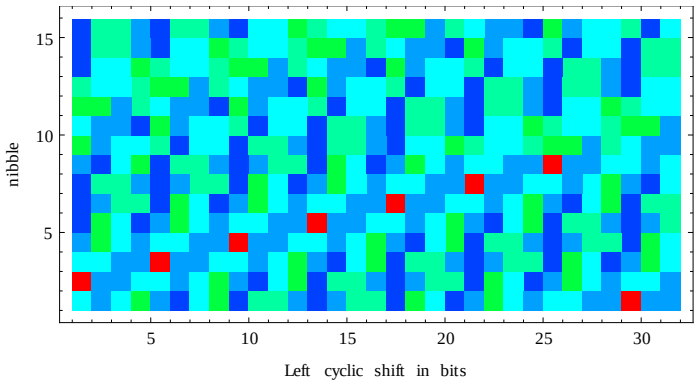
In[104]:=
```
MatrixForm[cyclichammings[[1]]]
```

Out[104]//MatrixForm=

0	18	18	16	16	18	16	12	18	20	16	12	20	14	14	18	20	18	14	14	20	12	16	20	18	12	16	1
16	16	18	18	0	18	18	16	16	18	16	12	18	20	16	12	20	14	14	18	20	18	14	14	20	12	16	2
18	12	16	18	16	16	18	18	0	18	18	16	16	18	16	12	18	20	16	12	20	14	14	18	20	18	14	1
20	12	16	20	18	12	16	18	16	16	18	18	0	18	18	16	16	18	16	12	18	20	16	12	20	14	14	1
20	18	14	14	20	12	16	20	18	12	16	18	16	16	18	18	0	18	18	16	16	18	16	12	18	20	16	1
20	14	14	18	20	18	14	14	20	12	16	20	18	12	16	18	16	16	18	18	0	18	18	16	16	18	16	1
18	20	16	12	20	14	14	18	20	18	14	14	20	12	16	20	18	12	16	18	16	16	18	18	0	18	18	1
16	18	16	12	18	20	16	12	20	14	14	18	20	18	14	14	20	12	16	20	18	12	16	18	16	16	18	1
16	18	18	20	12	18	16	16	14	20	16	16	20	14	14	18	20	14	14	18	20	16	16	12	14	16	16	1
12	12	18	14	16	18	18	20	12	18	16	16	14	20	16	16	20	14	14	18	20	14	14	18	20	16	16	1
14	16	16	14	12	12	18	14	16	18	18	20	12	18	16	16	14	20	16	16	20	14	14	18	20	14	14	1
20	16	16	12	14	16	16	14	12	12	18	14	16	18	18	20	12	18	16	16	14	20	16	16	20	14	14	1
20	14	14	18	20	16	16	12	14	16	16	14	12	12	18	14	16	18	18	20	12	18	16	16	14	20	16	1
20	14	14	18	20	14	14	18	20	16	16	12	14	16	16	14	12	12	18	14	16	18	18	20	12	18	16	1
14	20	16	16	20	14	14	18	20	14	14	18	20	16	16	12	14	16	16	14	12	12	18	14	16	18	18	2
12	18	16	16	14	20	16	16	20	14	14	18	20	14	14	18	20	16	16	12	14	16	16	14	12	12	18	1

In[126]:=
```
Print[ListDensityPlot[#, ColorFunction → hue32, InterpolationOrder → 0,
    ColorFunctionScaling → False, AspectRatio → 1 / 2, PlotRange → All,
    FrameLabel → {"Left cyclic shift in bits", "nibble"}]] & /@ cyclichammings;
```




nibble
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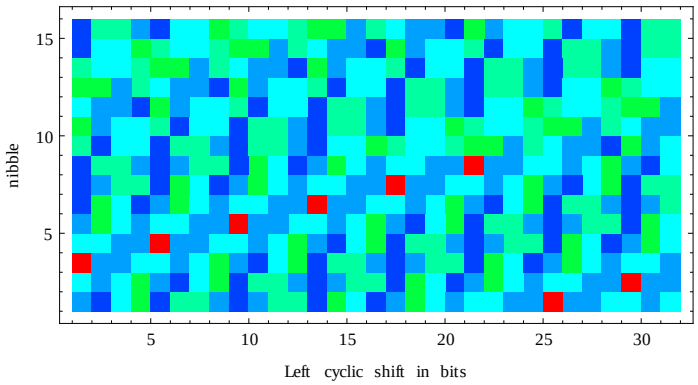
Left cyclic shift in bits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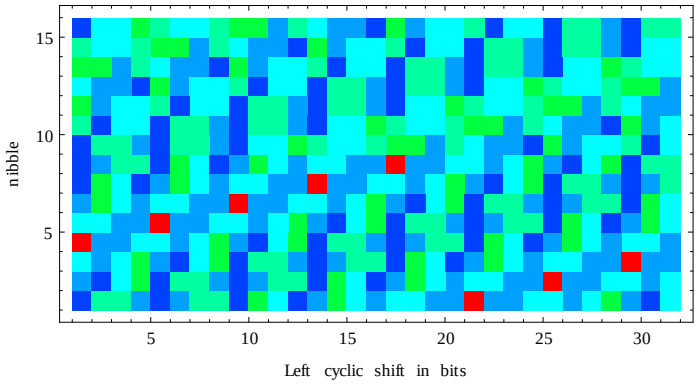
Left cyclic shift in bits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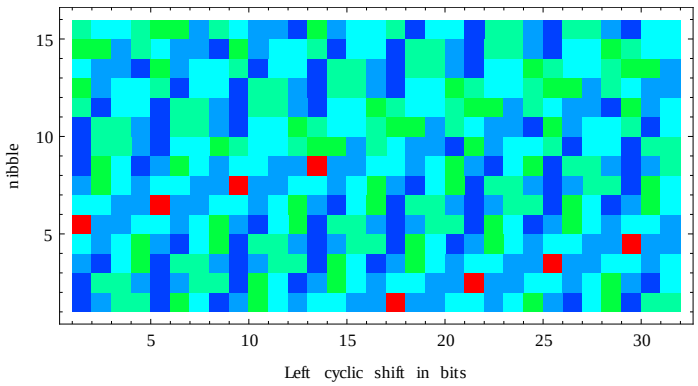
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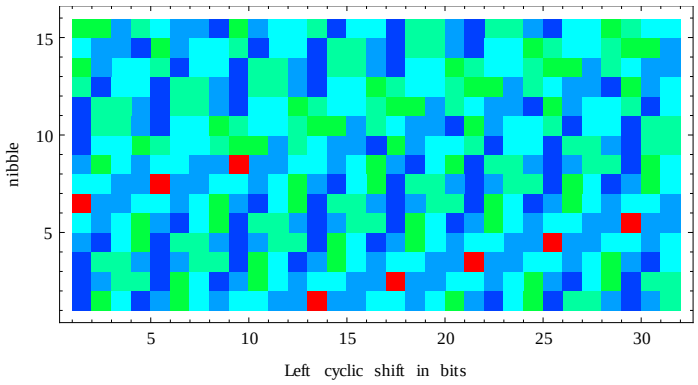
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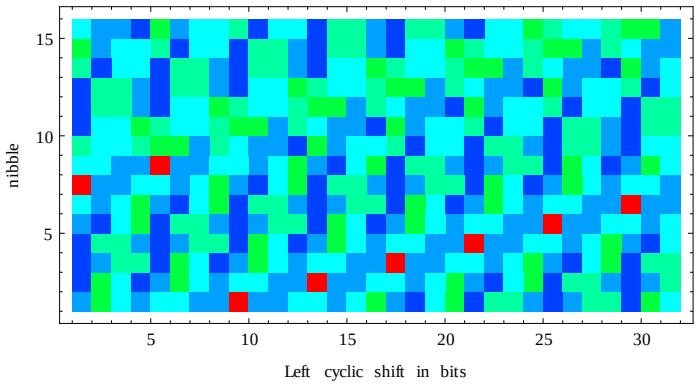
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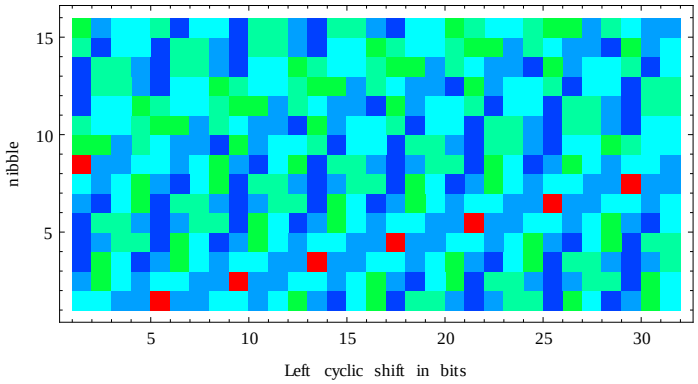
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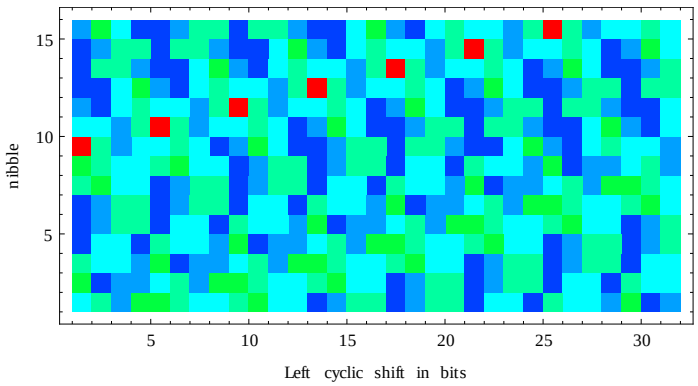
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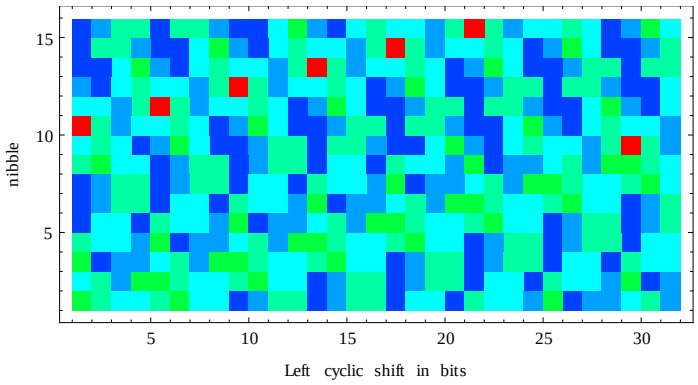
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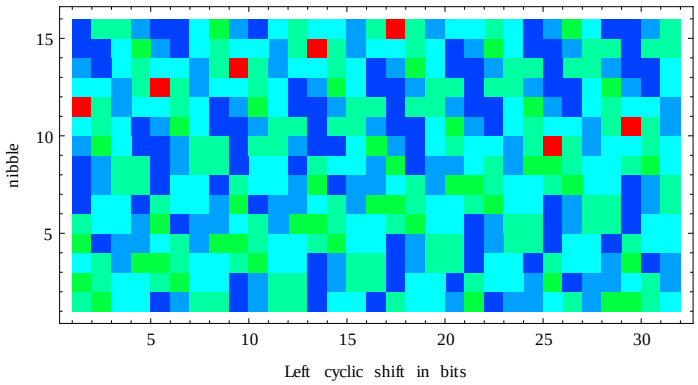
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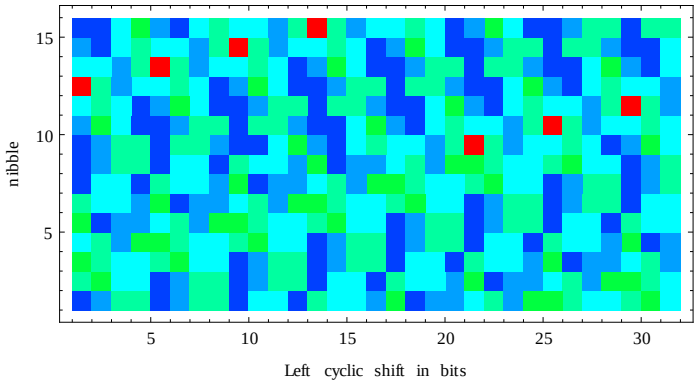
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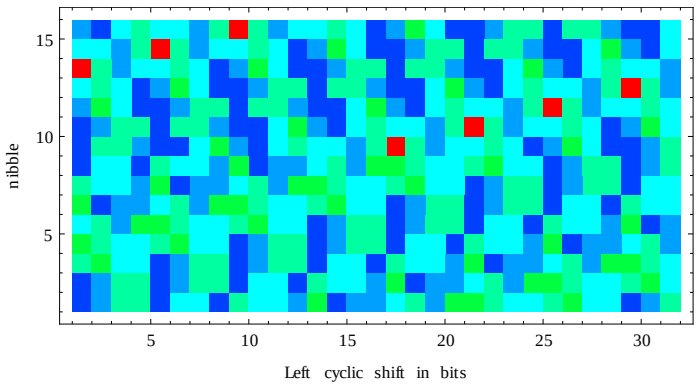
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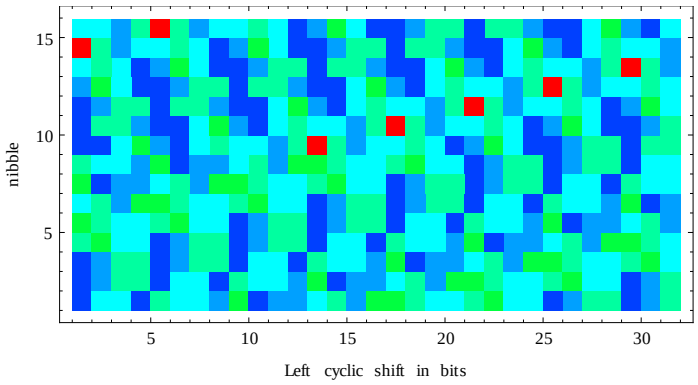
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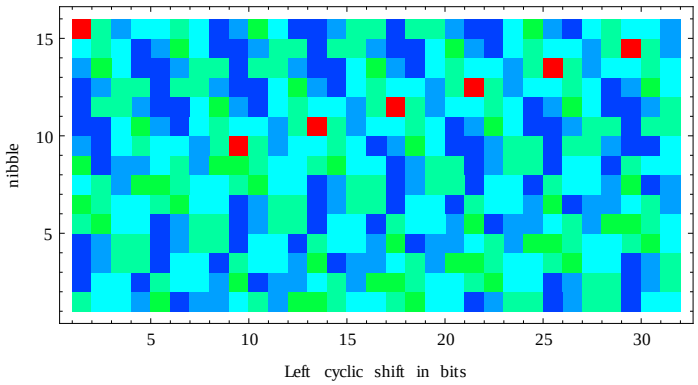
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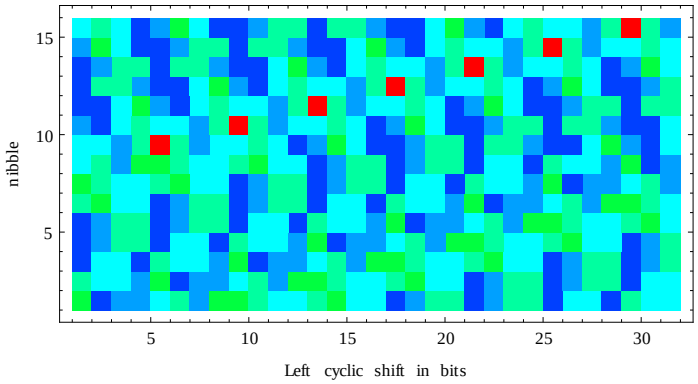
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